IEA 18 ADVANCED GLAZINGS

INTERNATIONAL ENERGY AGENCY
Solar Heating & Cooling Programme

TASK 18

ADVANCED GLAZING AND ASSOCIATED MATERIALS FOR SOLAR AND BUILDING APPLICATIONS

SUBTASK A **DRAFT FINAL REPORT**

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TASK 18
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FOR SOLAR AND BUILDING APPLICATIONS

SUBTASK A DRAFT FINAL REPORT

1 INTRODUCTION

1.1 Overview of Task 18

The objective of Task 18 is to develop the scientific, engineering and architectural basis which will support the appropriate development and use of advanced glazings and associated materials in buildings and other solar applications, with the aim of realising significant energy and environmental benefits. Task 18 is divided into two streams: Subtask A and Subtask B.

The projects identified for inclusion within Subtasks A and B are listed below:

Subtask A Applications Assessment and Technology Transfer

- A1 Applications, potentials and characteristics
- A2 Modelling & control strategies
- A4 Environmental and energy impacts
- A5 Applications guidance

Subtask B Case Study Projects

- B1 Monolithic and granular aerogels
- B2 Geometric media (honeycombs and capillary structures)
- B3 Chromogenic Glazings
- B4 Low-emittance coatings
- B5 Evacuated glazings
- B6 Advanced solar collector covers (subsequently dropped)
- B7 Angular-selective transmittance coatings
- B8 Light transport and holographic media (daylighting systems)
- B9 Frame and edge seal technology
- B10 Advanced glazings materials properties handbook and technology summaries
- B11 Investigation of the optical properties and scattering behaviour of advanced glazing materials
- B12 Measurement of the total energy transmittance of advanced glazing systems
- B13 Directional optical properties measurements of advanced glazing materials
- B14 Measurement of the U-value of advanced glazing systems

1.2 The need for Task 18

Since the Solar Heating & Cooling Programme began in 1974, exhaustive research & development had been carried out in many IEA countries on the energy performance of both the façades and the interiors of buildings – residential and commercial. At the conclusion of Task 10 it was clear that many promising advanced window systems remained to be explored and that a new, specific Task devoted to their investigation was justified.

Australia was in a unique position to contribute to the broader efforts of the IEA through a coordination of specific research projects that relate to current IEA activities. Most of the work traditionally undertaken in Europe and the USA has dealt with the problems of colder climates. In recent times however there has been growing interest in the temperate-climate problems of summer overheating of buildings, poor use of natural light, and issues related to thermal comfort. This has been the basis of much work in Australia for many years.

IEA Task 8 identified Advanced Windows (Glazing Systems) as being one of the major unresolved technical areas in energy-efficient and passive-solar building design (*Solar Update* No.13, p.8). The work of Task 10 has shown that Advanced Glazing Systems promise major energy savings in the future (*Solar Update* No.14, p.1). The program of work scheduled by Task 13 *Advanced Solar Houses* related to the development and testing of high-performance windows and other devices and products, to achieve minimum energy consumption in residential buildings.

The Project Definition Phase of Task 18 took place over 1991-92 and defined the new Task, *Advanced Glazing Systems for Solar & Building Applications*. Australia was represented from the beginning by one of the authors (JAB) who was awarded the leadership of Subtask A which concentrated on applications for advanced windows and ‘fast-tracking’ their adoption by end-users.

1.3 Project objectives

Subtask A of Task 18 focused on the application of advanced glazing systems in buildings and other solar energy systems. In order to facilitate technology transfer, it has been necessary to evaluate the energy and environmental benefits of the application of advanced glazings and their interaction with other aspects of building and systems design. This has involved the development of more credible methods of assessing the performance of buildings and systems containing advanced glazings.

The objectives of the work undertaken within Subtask A were:

- Investigation of the technical and economic potential of advanced glazing systems.
- Establishment of physical properties of advanced glazing materials and control strategies critical to performance.
- Evaluation of design tools and provision of applications guidance to aid the selection of advanced glazing systems.

- Study the climate dependence of performance, for defined building types and reference zones.
- Compare performance obtained with different materials.
- Assessment of cost and benefits and the setting of target costs against other solutions.
- Determination of the influence of degradation on energy performance.

Without a proper understanding of the potential energy benefits, appropriate applications and necessary performance requirements of advanced glazing materials it is difficult both to demonstrate the effectiveness and potential advantages which will result from the use of such materials. Similarly, energy benefits must be predicted to make educated choices in the selection of candidate glazing systems for either solar or building applications.. The results of Subtask A are of extreme importance to industry in making decisions related to product development, in the marketing of new products and in ensuring proper design selection, effective and appropriate application of the candidate materials.

To achieve the Subtask objectives, five projects (subsequently merged into four projects) were defined:

A1 ***Applications and Technology Transfer (Australia)***

A2/ A3 ***Modelling and Control Strategies (USA)***

A4 ***Environmental and energy impacts (Australia)***

A5/B10 ***Applications guidance and technology summaries (UK)***

2 OVERVIEW OF WINDOW ENERGY PERFORMANCE

2.1 A brief history of the window

Windows fulfil a more complex role in the envelope of a building than any other element. A balance must be found between often conflicting requirements of natural lighting, ventilation and a sense of 'connectedness' with the outdoors. In most parts of the world until the 1950s, windows mostly consisted of single panes of clear float glass mounted in steel or softwood frames. In fact float glass, with its great optical clarity and smoothness and its ability to be made in huge sheets, was the only major glazing technology advance this century up until that period. Originally developed by the Pilkington company, the float glass process was licensed to other manufacturers and quickly took over as the preferred method for making architectural glass.

Windows transmit energy quite easily compared with other parts of the building facade. Both radiant solar heat gain and thermal heat gains or losses may be ten times greater than through roofs, walls or floors. The manipulation (generally, a reduction) of these energy flows, to the benefit of the occupants of the building, has been the driving force behind Task 18.

2.2 Thermal verses solar performance: which is more important?

The short answer is: it depends on many factors. However these factors are now well understood. The thermal transmittance, or U-value, affects energy transfer which is driven solely by a temperature difference between indoors and outdoors. Conduction, convection and radiation all combine to cause a window to transmit heat from the warm side to the cold side. If there is a large temperature difference, it is worthwhile having a low U-value. In any climate where the average outdoor temperature is consistently above or below the human 'comfort band', a low U-value is an advantage. For other regions where temperatures are more benign, a low U-value is difficult to justify on economic grounds although there will be intermittent comfort benefits during seasonal extremes.

The 'best' amount of solar heat gain, caused when sunlight penetrates a window, also depends on climate. Solar heat gain is normally quantified by the total solar energy transmittance (TSET) or g-value, also know as the solar heat gain coefficient (SHGC). It is the fraction of radiant solar energy incident on the outside of a window that finds its way into the building. Most of this is transmitted directly, but a smaller proportion is due to solar energy which is absorbed in the glass and then re-radiated and convected into the room.

A high TSET in a cold climate will (in energy terms) outperform a low one, particularly if effective passive-solar design is used at the design stage of the building. Best performance is achieved if the window also has a low U-value because interior warmth will be conserved at the same time. In temperate and hot climates a large amount of solar heat gain must be avoided, especially in non-residential buildings which have little if any heating requirement except on cold mornings.

Control of radiant solar heat gain during mild to hot weather was dealt with traditionally by conventional eaves, fins, blinds, curtains and a variety of other attachments which certainly worked, but generally at the expense of daylight or views.

2.2 Physics of window energy flow

Most people are aware, at least intuitively, that heat energy may be transferred via conduction, convection and radiation. A fourth form of energy flow in buildings is via air leakage and ventilation. Engineers call this ‘mass transport’ because air is literally moving long distances and carries energy with it.

Increasing the ‘R-value’ (thermal resistance) of a building element reduces conduction directly and usually reduces convection as well, because insulators’ cells immobilise air. Insulating a wall or roof is desirable when weather conditions are frequently above or below the ‘comfort band’ of humans - say, between 18 and 27 ºC depending on relative humidity and the amount of air movement. Of course insulation slows but does not eliminate the ingress or egress of conducted heat to or from a building. Insulating the opaque parts of a building is straightforward provided the wall cavity is wide enough. Many countries define residential and commercial insulation levels as a form of minimum standard.

Walls, floors and roofs also block all solar direct radiation, although a fraction of what is absorbed will be conducted through, depending on the overall resistance. The term U-value (also variously referred to as U-factor or k-value) is normally applied to the overall thermal transmittance of a building component. It is measured in watts per square metre per Kelvin of temperature difference ($W/m^2.K$ or $Wm^{-2}K^{-1}$) where one Kelvin (1K) is the same as a change of 1 ºC. It is worth noting that the U-value is normally quoted in the context of the whole wall, roof, etc. The U-value is simply the inverse of the R-value.

Insulating walls and roofs is easy because bulk insulation is cheap and effective. Depending on the severity of the climate, R-values up to 6 or more are used in ceilings which implies an overall U-value of less than 0.17 once the effect of the ceiling, the roof air space, the roofing material, etc is included.

Now consider windows. The simplest window is a pane of clear glass, or perhaps two panes separated by an air gap between 6 and 20 mm wide. The U-value of a single-glazed window is of order 5 to 6 $W/m^2.K$, or at least ten times greater than the insulated wall! Heat is transferred by conduction throught the glass, convection from its surfaces and radiation from those surfaces. The corresponding window R-value is in the range 0.15-0.20, of which only a few percent is actually due to the glass itself. Installing thicker glass won’t keep a house warmer in winter, contrary to popular myth in some countries. In fact over 95% of the meagre thermal resistance provided by a window is actually due to the ‘air films’ that cling to the two surfaces. These air films become even less effective if there is a breeze. With two panes, a still air space as added so that the net result is that the R-value is roughly doubled; i.e. the U-value is halved. From this discussion so far it is apparent that in terms of thermal insulation, window are gaping holes in the fabric of a building. They are no more effective than tissue paper or thin plywood.

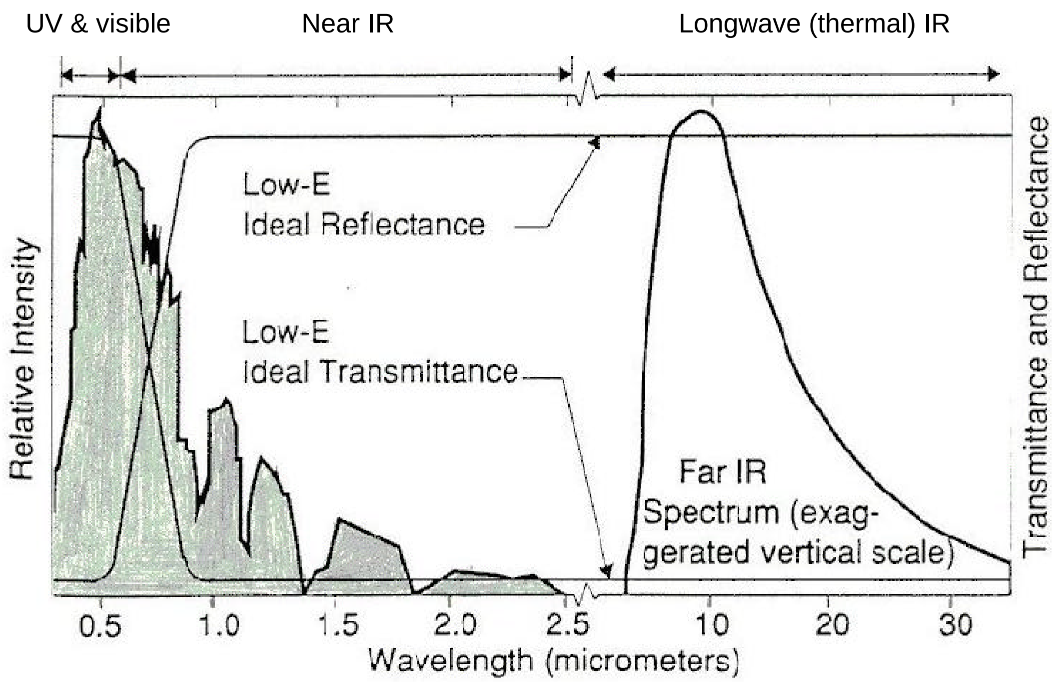

Figure 1. The terrestrial solar spectrum with ultraviolet, visible and near infrared bands and the optics of ideal solar-control glass (low TSET).

Clear glass is transparent to all radiant energy from the Sun. This is called shortwave radiation and occurs at wavelengths between about 0.3 micrometres (µm), in the ultraviolet part of the spectrum, and 2.5 µm[1] . The solar spectrum consists of UV radiation (not really 'light', since it is not visible to the human eye), from about 0.2 µm to 0.4 µm, followed by visible light from approximately 0.4 to 0.7 µm and finally invisible near-infrared radiation (NIR), between 0.7 µm and 2.5 µm. In terms of relative energy content, the three portions of the spectrum are divided roughly in the ratios 3%:47%:50% respectively. Ordinary clear glass is undiscriminating and passes all three bands with approximately equal ease. Once inside a building, a small amount is reflected out again (depending on the colours inside the room) but the rest is converted to heat that we can feel but not see - so-called longwave radiation. The wavelengths of such radiation are large - between 5 and 50 µm.

Longwave electromagnetic energy cannot pass directly through glass but heat still enters or leaves because the long-wave energy warms the glass; this heat flows to the other side and is carried away by various means.

[1] The older term *micron* is sometimes still used although it is discouraged in the SI system of units. 1 µm = 1000 nanometres (nm) where 1 nm = 10^{-9} m.

2.3 Technology options for controlling the energy behaviour of windows

To reduce the heat flow arising from a temperature difference across the glass, the U-value must be reduced. Methods include:

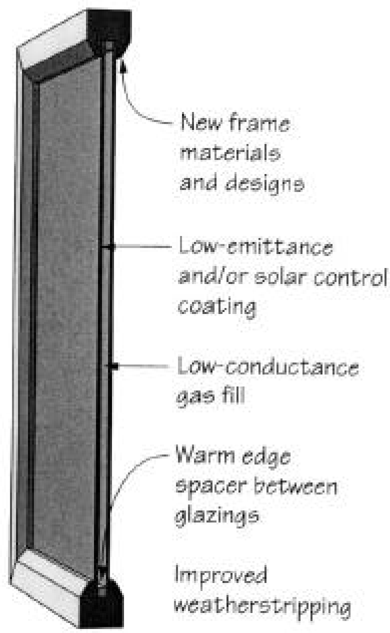

Figure 2. Technological advances have significantly improved window energy performance in recent years. Reproduced by permission from Carmody *et al* (1996).

- more glazing layers. Almost all multiple glazing comes in the form of factory-sealed insulating glass (IG) units which are glazed into the window frame as a single unit. In practice more than three glazing layers is cumbersome and very expensive;
- in multiple glazing, replacing the air with a vacuum (ideal, but still at the R&D stage), or a low-conductivity gas such as argon (cheap) or krypton (expensive);
- employing other filling materials between the panes such as aerogel, plastic capillaries, transparent honeycomb, or other media which transmit solar energy (visible and invisible) but reduce convective and conductive heat transfer across the glazing unit;
- covering the window with curtains, a blind, or similar device which seals around the edges. This will trap a layer of air and thus function like an extra glazing layer, but only when drawn over the glass;
- applying an invisible thin-film coating to the glass which passes most of the light but reflects longwave radiation. This is literally a heat mirror, otherwise loosely referred to as a low-emittance (low-e) coating[2]. A low-e coating is a microscopically thin, near-invisible layer using metal(s) or metal oxides. The most common metals are silver, platinum and gold. A low-emittance surface is at one time a good reflector, a poor absorber and a poor emitter of radiant heat - like a silver teapot, which cools more slowly than one made of porcelain. Conversely, a high-emittance surface absorbs and radiates heat efficiently. The perfect radiator is known as a 'black body' and has an emittance of 1.0 while plain uncoated glass has an emittance of 0.84. An emittance of zero means the object cannot radiate heat at all and is a perfect reflector. Most solid objects possess emittances in the range 0.8 to 0.9, regardless of colour. The object of a low-e coating is to reduce the surface emittance of glass as much as possible. Low-e coatings are best applied by the glass manufacturer but may also take the form of an upgrade (retrofit) stick-on film. In simple terms, low-e coatings reflect heat back into a room in winter and may also reflect it away in summer. Except for stick-on films, low-e coatings are almost always employed in a double-glazed form, as protection from abrasion and attack by moisture, airborne pollutants, etc. In typical

[2] Also known as a *low-emissivity coating*.

double-glazed units, the coated side is either the second or third surface (counting from the outside in).

Table 1. Indicative thermal, solar, visible and 'cool daylighting' performance of the seven glazing types. The bigger the number in the last column, the better the light-to-heat ratio of the window. Figures evaluated using WINDOW 4.1 computer program (LBNL 1994)

Glazing type	U-value ($W/m^2.K$)	TSET	b (SC)	T_{vis}	K_e
Clear 3mm	5.5	0.86	1.00	0.90	0.90
Selective green 6mm	5.5	0.53	0.61	0.66	1.08
Clear double 4/12/4	2.8	0.77	0.88	0.81	0.92
Double with low-e on 2nd surface (high TSET for passive solar gain) and argon gas	1.6	0.69	0.79	0.74	0.94
Double with grey outer pane	5.4	0.28	0.33	0.15	0.45
Double with low-e on 3rd surface and argon gas fill (low TSET for solar control)	1.4	0.27	0.31	0.56	1.81
Vacuum glazing with high-TSET coatings on 2nd and 3rd surfaces	1.2	0.62	0.72	0.69	1.11

other gas) in the space remains dry. Conventional insulating glass units are **not** evacuated.

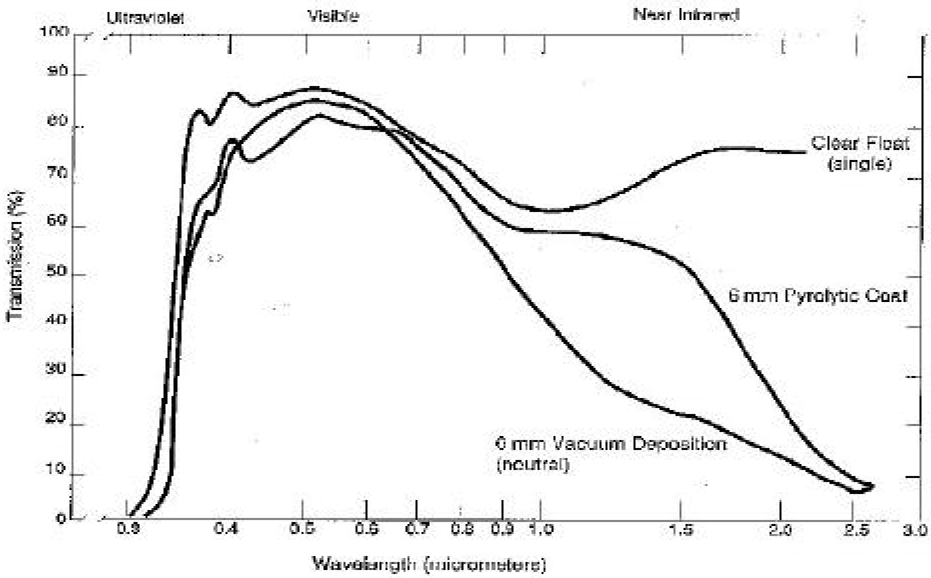

Figure 3. Spectral behaviour of pyrolytic and sputtered low-e coatings compared to clear glass.

Table 1 shows what can be achieved. From an initial U-value of 5.5 for clear glass, this may be reduced to less than 2 using a combination of measures to reduce all three forms of heat transfer. The best ‘superwindows’ attain U-values of 1 or less, at a cost, and employ up to four glazing layers, several of which have low-e coatings on one of their surfaces. If high-volume production of vacuum glazing becomes reality, such ultra-low U-values may become routine.

To control solar heat gain through a window we may:

- shade it.This is traditional and effective but has drawbacks as discussed earlier;
- tint it. A colorant (pigment) is introduced into the molten glass during manufacture. Such ‘body tints’ absorb some solar radiation and reduce overall heat gain;
- apply a surface coating in the form of either a mirror-like metal film which unselectively blocks light as well as solar near infrared, or a selective low-e film which preserves most light transmission. Glass coating plants using the patented Airco™ sputtering process have the ability to produce a selectively ‘tuned’ low-e coating so that more or less of the near infrared is transmitted, depending upon the desirability of passive solar gain in the final application. Such multilayer coatings are flexible in their characteristics but are relatively expensive to produce. They are also easily scratched and have a shelf life of a few months at most. For this reason they must be employed in an insulating glass form, for protection. Very low emittances down to 0.04 can be achieved.
- employ a so-called hard coat which is based on a metal oxide that is sprayed onto the glass while it is on the production float line and still hot. The pyrolytic coating bakes into the glass surface and results in a very tough layer which may be handled later without damage. Hard coats can used in ‘monolithic’ (single-glazed) form although this is unusual. Their main advantage is simplicity and thus relatively lower

cost; the main disadvantage is less control over the final transmittance characteristics. Pyrolytic coatings allow high solar gain and also have emittances in the range 0.15-0.35, much higher than the best soft coats. However even the worst pyrolytic coating is a big improvement over uncoated glass;

- employ an electrochromic glazing whose optical and solar properties may be controlled using an electrical signal. The switchable properties of the glass are determined by the presence of a multilayer coating which behave like a thin-film battery in reverse. By using a building's energy management system to dynamically control the amount of daylight and solar heat gain admitted by the window, the impact of the window may be tuned to the climate, time of day, and needs of the occupants. Very large savings in operational energy are possible with the use of switchable windows.

It might appear that hard low-e coats are unsuited to solar-control applications, because their TSET is quite high. However they still possess a high reflectance to longwave radiation (low emittance) and are therefore 'reluctant emitters'. If such a coating is applied to a body-tinted glazing the result is a system which has low solar transmission (see Figure 3). The solar energy that is absorbed in the tinted glass has only one place to go - back to the outside. Another variant on this approach is to laminate clear hard-coat low-e glass with another piece of tinted glass, with the low-e coating is on the final inside-facing surface.

The issues of architectural design and glass technology should never be divorced. Even in a cold climate, a large west-facing window positioned to take advantage of a view will create less summer discomfort if it has a low-e coating with low solar transmission. However the trade-off is that it will admit very little useful solar heat gain in the winter.

2.4 Windows and daylighting

A very useful index of the daylighting potential of a glazing system is the so-called *luminous efficacy (K_e)*, found by dividing the visible transmittance by the total solar energy transmittance:

$$K_e = T_v / TSET$$

The greater this ratio the better, as in indicates that the glazing is better at transmitting light than heat. K_e-values exceeding 1.5 are possible with the most selective 'cool daylight' glass types. Some examples of K_e for common glass types are given in Table 1. These retain light transmission while greatly reducing solar heat gain. Such glazings should be linked to dimming systems in non-residential buildings so that daylight displaces electric lighting, thus minimising the heat load imposed on the building.

In California, Pacific Gas and Electric offers electricity discounts to commercial building owners who install glazing with a high luminous efficacy (Schumann, 1992). Such incentive schemes help energy utilities in their demand-side management objectives and save customers' money. If high-performance (particularly electrochromic) glazing with linked daylighting is used in non-residential buildings, the additional cost of the windows can be *largely* offset by the savings gained through smaller mechanical systems, because cooling needs are reduced.

2.5 Infiltration and ventilation

The quality of window weather-stripping varies widely, as does its impact on heating and cooling needs. Some air replacement is essential to remove indoor pollutants ans thereby maintain indoor air quality. Half an air-chage per hour is generally adequate. In predominantly temperate climates, small to moderate leakage does not increase heating and cooling energy needs by more than a few percent. Several companies market ‘trickle’ ventilators that allow permanent low-level ventilation, usually at one edge of an operable sash. It is recommended that windows be selected that conform to the local relevant building standards. For example in Australia and the United States, infiltration must be below 1 L/s.m^2 for air-conditioned buildings, or otherwise less than 5 L/s.m^2 for non-air conditioned buildings.

2.6 The fade-causing behaviour of windows

The light that window glazing transmits is responsible for much interior damage . Fading damage to fabrics and surface finishes is due in approximately equal measure to ultraviolet radiation and also shortwave visible light, mainly at the violet and blue end of the visible spectrum. Glazing materials are highly transparent to both bands (see Figure 3), *including* most glazings with low-e coatings. A few glazing types incorporate selective coatings or plastic interlayers (particularly laminated glass) which block up to 99% of UV radiation. However contrary to popular impressions, that this will only halve the fading damage, not eliminate it. Further fade reduction can only be achieved by the use of body tints in the glass or by shading, both of which reduce visible light substantially. Because fading damage is an important consumer issue in Australia, the *new Window Energy Rating Scheme* includes a *Fade Prevention Index* which enables different products to be compared in terms of their fading impact, on a fair and independent basis. The fading transmttance is estimated from a combination of ultraviolet and visible light, weighted according to the Krochmann Damage Function and calculated by the computer program WINDOW 4.1 (LBNL 1994).

2.7 *Glass temperatures and human comfort*

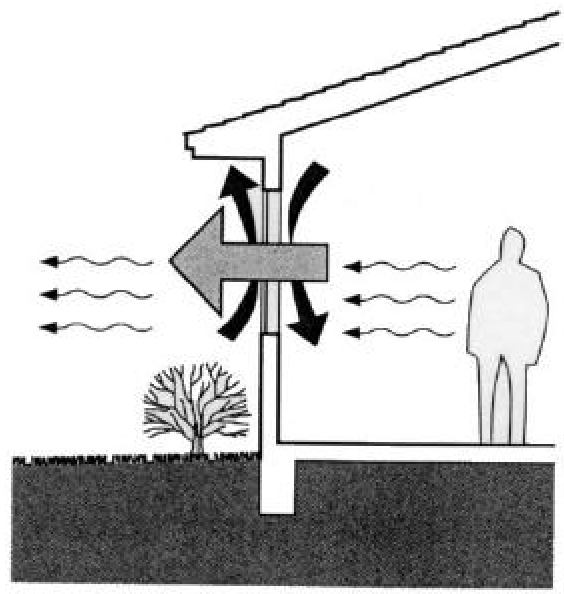

Figure 4. Comfort in winter is influenced by conduction, convection and radiation. Reproduced by permission from Carmody *et al* (1996).

The perception of comfort by a person depends not just on air temperature but on the temperature of the surrounding surfaces. The 'mean radiant temperature' exerts a large effect when the person is close to the window. It is a matter of which way is the net radiation going: from the glass to the person or vice versa? In winter, any measure which raises the surface temperature of the window system towards that of the ambient air will have a positive effect. Curtains, double glazing, low-e coatings or even a lightweight blind will all help. In the latter case, the blind functions as a 'radiation shield' but does little to address conductive heat loss itself. In summer, heavily tinted glass can cause extreme discomfort because it becomes a hot radiator when exposed to direct sunlight. With single glazing, temperatures in excess of 60ºC are common. This is bad design - if the window cannot be shaded the occupants should be protected by a second pane which acts as a buffer (viz. double glazing with the tinted glass being to the outside). An alternative is to employ a selective low-e coating on the second surface of a clear pane which rejects solar heat rather than absorbing it in the way that tinted glazings do.

2 ENVIRONMENTAL IMPACT

3.1 Introduction

By the 1980s, concerns about fossil-fuel energy use and global warming had spurred new building standards, energy codes and building products in many industrialised countries. The practice of solar-efficient design principles by a few brave designers showed that a house or a commercial building could exist in relative balance with its environment while minimising energy consumption for heating, cooling and lighting. Yet even with optimal orientation and the widespread use of roof and wall insulation it was clear that windows were lagging badly, in terms of their associated operational energy and the resources required to manufacture, maintain and dispose of them.

The environmental brief for the window designer and specifier is that:

- the window should have a net impact, in terms of energy and its effect on the occupants of the building, which is at least neutral and preferably positive, compared with using an insulated wall of the same area;
- the manufacture, installation, operation, maintenance and ultimate decommissioning of the window should impose the smallest possible adverse affects on the environment.

3.2 Projected energy and environmental benefits of advanced glazings

3.2.1 Operational energy – residential

Project A4 of Task 18, *Environmental and Energy Impacts*, has projected that significant benefits in energy savings and resultant CO_2 emissions should accrue from the use of advanced glazing and window technologies. The optimal applications are country- and climate-specific and the final CO_2 emissions depend on differences in the sources of energy and associated improvements in technology.

Generally, the predicted *whole-building* energy savings for heating, cooling and lighting achievable with advanced window technologies range between 20% and 40% according to the results of Task 18's Project A2/A3 *Modelling and Control Strategies*. Once the anticipated energy savings are known, the associated reductions in CO_2 emissions can be readily calculated for each country if their emissions in kilograms of CO_2 per gigajoule of energy are known.

Even the use of current-technology glazings which are superior in performance to the average product used today can lead to major reductions in building energy use. For example, Australia's *Window Energy Rating Scheme* predicts the benefits (shown in Figure 5) from the use of the better windows which are already available. The relative energy savings exceed 25% for heating and 40% for cooling when the best-performing products are substituted for clear single glazing. The National Fenestration Rating Council (NFRC) in the USA and the Canada's ER Scheme for residential window rating also show operational energy benefits of similar or greater relative magnitude when current ‘high end’ windows are installed.

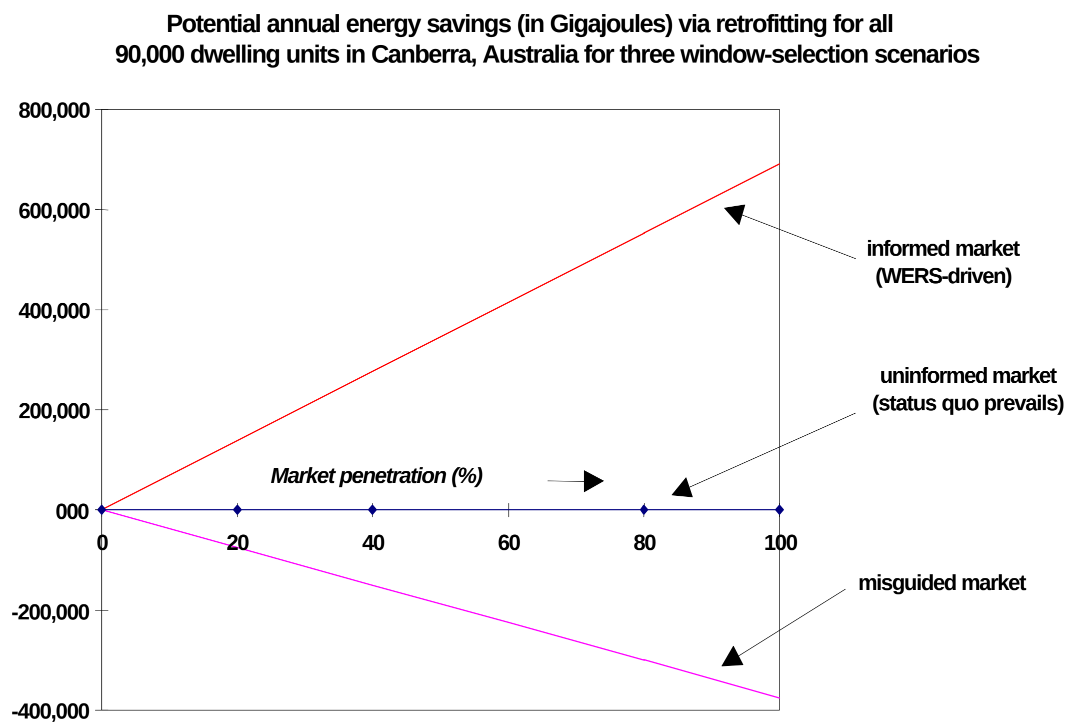

Figure 5. Limiting scenarios for Canberra (population 300,000) corresponding to best-case, to predominant current practice and to worst-case selection of windows. The best-case windows are double-glazed with one pyrolytic low-E coat and a wood frame [U = 1.8W/m^2.K , TSET = 0.60], the current practice is clear single-glazed with an unbroken aluminium frame [U = 5.7W/m^2.K , TSET = 0.90] while the worst-case windows are single-glazed reflective with an unbroken aluminium frame (U = 5.7 W/m^2.K, TSET = 0.36). WERS is the Window Energy Rating Scheme.

Conservatively, about US$6 million in energy costs could be saved in the ideal scenario. In contrast, several million dollars extra per year could be wasted by Canberra homeowners in the worst-case scenario.

The potential energy savings resulting from the use of advanced glazings depend on the mix of building types and their uses (including many human factors). For residential buildings, the table below (taken from the final report for Project A4 Environmental and Energy Impacts) gives a breakdown for four different countries which participated in Task 18.

Table 2. Average mix of residential building types for four countries Task 18 countries.

	Building type		
Country	Free-standing house	Terrace house	Multistorey apartment
Denmark	49	8	43
Finland	58	13	29
Norway	73	0.5	26
Australia	80	7	12

Free-standing houses are the most climate-dominated and multistorey apartments the least, and therefore advanced windows offer the greatest energy-saving potential in the first case.

3.2.2 Operational energy - non-residential

Advanced glazing systems in commercial buildings can also be expected to offer large energy savings. Reduction as great as 35% in hot dry climates are predicted (see also B3 - Chromogenic Glazings). Overwhelmingly, project A2/A3 has predicted that electrochromic (optically switchable) windows are most effective in situations dominated by cooling rather than heating loads. Because cost-benefit analyses suggest that the most cheapest choice of advanced window technology is not necessarily the most energy-conserving, it was also vital to perform lifecycle calculations so that all energy and cost inputs were accounted for.

3.3 Embodied energy

Worldwide, the total area of glazing in the commercial sector is substantially less than in the residential sector and there are also different energy demands between the two sectors. The facade of a modern commercial building contributes only 15-20% of the embodied energy of the building although some recent studies have shown that the embodied energy of the *whole* of a commercial buildings over a 40-year life including refurbishments, may exceed the operational energy. Facade coating materials and their application technologies are generally very energy-intensive but because so little of such materials are used they add little (<1%) to the embodied energy of building facades. The embodied energy of the windows is very small (<1%) compared to the potential operational energy saving over the life of the buildings, say 40 years.

4 SUMMARY OUTCOMES OF SUBTASK A PROJECTS

4.1 PROJECT A1 - Applications, Potentials & Characteristics

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Goals of Project A1

The project's aims as set out the Task 18 Technical Annex, January 1992 were to develop a framework for guiding the research, development and application of advanced glazing materials. This process involves the definition of the terms and parameters used to describe glazing systems and the identification of suitable applications so that advanced glazing systems would realise significant economic, comfort and environmental benefits.

Goals of A1 were to:

1. Identify and define the parameters required to characterise advanced glazing materials and glazing systems.
2. Review the required form for presentation of data so that designers are provided with the necessary information to allow the adequate specification of new products.
3. Review the aesthetic acceptability of specific advanced glazing materials.
4. Identify constraints and limits on the application of advanced glazing materials such as cost, availability, framing technology, long term performance, aesthetics etc.
5. Identify appropriate applications and establish basic performance data.

The following publications were produced in Project A1:

T18/A1/UK2/93
Comments on definitions of key glazing performance parameters
Adamu A & Marshall RH, 1993

T18/A1/UK1/94
Technical and economic potential of advanced glazings
Robinson PD, 1994

T18/A1/WD2/94
Visual amenity factors related to advanced glazings

Aschehoug Ø, 1994

T18/A1/WD3/94

Glossary of glazing terms

Lyons PRL, Hutchins MG & Marshall RH, 1994

T18/A1/WD1/95

Identification & definition of key glazing performance parameters

Lyons PRL, Prasad D K & Ballinger JA, 1995

The report by Adamu and Marshall (UK2) consisted of critical contributions which were taken into account in the final WD1 report on glazing parameters. Therefore it will not be considered separately here.

Summary of achievements

Goal 1:

T18/A1/WD3/95 - *Glossary of terms*

This document was completed in January 1995 and presented in final form at the 6th Experts' Meeting. It defines over 150 glazing, window and window-related architectural terms. The content has been published as a conventional printed document and also as a database using Microsoft Access. To improve the usefulness of the glossary, the definitions have been categorised and cross-referenced to relevant Task 18 and other projects and to international standards

T18/A1/WD1/95 - *Identification and definition of key glazing performance parameters*

This document is divided into two main sections. The first section presents an overview of the categories of parameters needed to describe the energy behaviour of windows. The discussion explains the historical development of modern computer programs which perform dynamic simulations of the energy flows across the envelope of a building and the use of these parameters in such calculations. The second section defines all parameters in current usage and makes use of tabular and graphical formats. Particular attention is paid to the total solar energy transmittance (TSET) and shading coefficient because of their inherent complexity and potential confusion caused by the number of variations in common use in different countries. Because TSET is a strong function of convective effects in addition to glazing optical properties, the paper reviews the more common empirical expressions for convective film coefficients in some detail. In particular is it concluded that where locally realistic residential TSET values are to be predicted (as distinct from assigning arbitrary 'standard' conditions), great care should be taken in the choice of expression for the film coefficients

T18/B14/WD2/94 - *Survey of standards and semi-standards on thermal and solar properties of glazings and windows*

This report by the Netherlands is a worldwide compendium of methods for calculation and measurement of all energy-related window parameters. It references, where possible, the relevant ISO, CEN, ASTM and other standards and procedures for these parameters

Goal 2:

Broadly speaking, this goal was achieved. By examining which parameters which best describe both the instantaneous energy performance and the annual energy impacts of windows, the task's outcomes may be processed into forms which assist industry on the most effective data to use in applications-guidance material. An even more derived form of materials is for the energy rating and labelling of windows, a process which is maturing in North America and Australasia.

Goal 3:

T18/A1/WD2/94 - *Visual amenity factors related to advanced glazings*

This document addresses visual issues of advanced glazing materials. It is based on a study by Lien (1994)[3] which is an archetypal study examining most factors that influence visual amenity: It covers many of the concerns that architects should have about the impact of a glazing system on the quality and distribution of light in a room and on the environment around the building. As pointed out in the report, two other major applications of advanced glazings are in solar collector covers and solar (thermal storage) wall covers. However these applications do not give rise to the same visual concerns as view or daylighting windows.

5.2 PROJECT A2/A3 - Modelling and Control Strategies

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Project A2/A3, *Modelling and Control Strategies*, was carried out to evaluate the energy and comfort performance of advanced glazings in commercial and residential buildings. Eleven participating countries in Task 18 have performed simulations of candidate glazing systems covering a very wide range of climates. All studies compare typical current technology with near-term advanced glazings where the 'base case' window varies from single-glazed clear in a thermally unbroken aluminium frame in the case of the United States and Australia to double-glazed clear in a wood frame for the colder

[3] Lien, A.G. *A Visual, Qualitative Study of Transparent Insulation Materials.* Division of Building Technology, Department of Architecture, Norwegian Institute of Technology, Trondheim, January 1994.

countries. The most advanced glazings were generally vacuum, aerogel and aerogel systems. Vacuum windows are now commercially available in Japan, as described in Section 7.4 of this report. Aerogel windows are still at the development stage but are expected to be on the market by the end of the decade.

It is not the role of this report to repeat all the findings of above studies, however some of the key findings are very instructive. The most extensive of these simulations were reported in a paper presented at Window Innovations '95 in Toronto, Canada, held to coincide with the 7th Experts' Meeting of Task 18[4]. The paper contains results from Australia, Finland, Norway, Switzerland and the United States. Some studies included economic calculations to assess the competing window types from a cost-effectiveness viewpoint as well as a purely energy viewpoint. The Norwegian studies included economic analyses which calculated the Net Present Value of the alternative window types. Cost effectiveness was assessed by the difference between the present value of the energy savings and the investment cost of the particular glazing. A positive value signifies a positive investment.

Residential studies - conclusions from A2/A3

All countries' results confirm that the annual energy performance of windows is highly climate-dependent and is a complex function of the tradeoffs between solar heat gain and thermal insulation, especially for houses, which tend to be far more climate-dominated than office buildings. One characteristic may be maximised for a particular application, but generally at some cost to the other. From a cost-effectiveness viewpoint in Norway, a low U-value is more important than high solar transmittance because of the limited benefits to be obtained from passive-solar design in long, dull northern winters. Overall, double low-e with argon gas fill is the most cost-effective choice at current energy prices. The clear low-e vacuum windows actually yield the lowest heating energy needs because of an increase in solar heat gain compared to triple or quadruple conventional windows, but were not analysed for cost-effectiveness because reliable retail prices were not available at the time of the study.[5] Interestingly, the results for Finland, another high-latitude country, showed that the benefit of a very low U-value is largely cancelled by the drop in total solar transmittance, which reduces useful solar gain in winter.

The milder climates such as Switzerland, the United States and Australia showed that retaining passive gain in winter is very important and should not be 'sacrificed' simply to reduce the U-value. For equator-facing facades in all countries, all the low-e glazings outperform insulated walls with no windows. The selection of suitable windows for a given building type and climate is best achieved using consumer-oriented rating and labelling schemes, such as those now operating in The United States, Canada and Australia.

Simulations show that summer (cooling) energy needs are a strong function of the solar transmittance of the window. In warm to hot climates, high-performance single glazings

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[4] Sullivan R. et al., *Energy Simulation Studies in IEA/SHC Task 18, Advanced Glazing and Associated Materials For Solar and Building Applications,* Proc. Window Innovations '95, 635-690 Toronto, Canada, June 1995.

[5] A preliminary cost/benefit study may be found in Garrison J.D and Collins R.E., *Manufacture and cost of vacuum glazing,* Solar Energy Journal, <u>55</u>, 3, 151-162, September 1995.

can perform best overall because their good solar rejection is more beneficial than a very low U-value. The simulation of electrochromic glazings in Florida and Arizona, both hot regions of the United States, shows that electrochromics can compare well with conventional, shaded clear low-e glazings. The choice of control strategy is important - i.e. the means by which the switching behaviour is triggered. Space cooling load appears to be the best control choice.

In very hot climates where ambient temperatures, coupled with high humidity, are nearly always outside the human 'comfort band', optimum energy performance is obtained from windows which minimise the thermal transmittance as well as the solar heat gain. This points to switchable double-glazed units offering the best performance.

Commercial studies – conclusions from A3/A3

Most non-residential buildings tend to be dominated in their internal conditions by solar heat gains and by heat loads from lighting, people and equipment. Advanced glazings assist in reducing unwanted heat gain and preserve visible light transmittance by means of selective 'cool daylight' low-e coatings. Finland and the United States presented simulations results for office buildings in the paper described above. Among conventional static glazings in Finland, a triple unit with TSET = 0.40 and U = 1.33 yielded the lowest cooling energy needs for all orientations. The benefits of daylighting were not considered. The United States simulations were for hot dry southern California and found that best performance occurred with low-e reflective electrochromic glazings having deliberate daylighting strategies with linking dimming controls on electric lighting. Such a system easily results in the lowest total annual energy needs for cooling, fans and lighting.

5.3 PROJECT A4 - Environmental and Energy Impacts

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The following publications were produced during the A4 project:

Publication code	Title	Author	Date
T18/A4/AUS1/94	Materials and environmental impacts	Lawson WR	1994
T18/A4/AUS2/95	Some window life-cycle issues	Lawson WR	1995
T18/A4/FRA1/95	Use of LCA for the measurement of building products environmental quality	Le Teno JF	1995
T18/A4/SP1/95	Study of the energy consumption of office buildings in Spain	Cordoba J	1995
T18/A4/WD1/96	Life cycle analysis of materials used in advanced glazing systems	Lawson WR	1996
T18/A4/SP2/96	Energy consumption assessment in apartment buildings	Cordoba J	1996
T18/A4/FIN1/96	Environmental impacts of manufacturing and use of Finnish type window	Saarni R and Aatola M	1996

Conclusions from A4

Project A4 has indicated that significant benefits in energy saving and lowered resultant CO_2 emissions may accrue from the use of advanced glazing and window technologies. The optimal applications are country/climate specific and differences in sources of energy, and associated improvement in technology, significantly affect CO_2 emissions.

Environmental and ecological impacts associated with the procurement of materials used in advanced glazing systems have been indicated and the significance of recycling of materials, facilitated by *Design for Deconstruction* (DFD), in minimising undesirable impacts and sustainable production have been outlined.

5.4 PROJECT A5/B10 - Applications Guidance and Technology Transfer

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This project collated important results into applications-guidance material that can be incorporated into the dissemination programs of each participating country taking account of differences in climate and construction techniques.

The main areas of activity within A5/B10 are listed here:

1. Preparation of a teaching and learning package for educationalists
2. Preparation of technology summaries
3. Generation of an advanced glazing materials database
4. Preparation of a glazing materials properties handbook
5. Development of an advanced glazings glossary
6. Formation of national industry clubs
7. Publication of national newsletters
8. Publication of a Task bibliography
9. Organisation of national and international conferences and industry workshops
10. Preparation of a Task 18 brochure, exhibition and display material
11. Preparation of a Task 18 video

Conclusions from A5/B10

The technology of window systems has advanced greatly in the last ten years. Many exciting technologies have emerged which have the promise, if applied wisely, to realise significant economic, comfort and environmental benefits for buildings and their owners and users. By now the process of coordinating basic and application research is quite mature, with structured projects being undertaken by many OECD members (e.g. Canada, USA, Japan, Europe, Australia). These projects are carried out at a local level to help realise local goals, such as those of the National Fenestration Rating Council, or the Joule II Programme of the European Union, but are also coordinated internationally through projects like Task 18. Such projects are largely supported by government research funding to address identified priority areas in pure and applied science and the environment, for example. Sponsorship from other stakeholders such as manufacturers and energy utilities is becoming increasingly important also.

However, many challenges must be overcome if high-performance windows are to achieve a significant share in the marketplace by the year 2000. The problems include high initial cost, lack of knowledge, and great conservatism in industry and among the diverse market - architects, building engineers, window specifiers, building owners and occupants.

The recent recession slowed new building construction and made building owners and home-builders and buyers very cost-sensitive. The retrofit market is vast and largely untapped in Australia. Incentive programs are normally required to encourage the adoption of better products. A partnership of prescriptive regulation and financial “carrot and stick” measures must be developed in each region. Another strategy is to integrate exemplary energy performance into the quality assurance programs which cover non-energy issues such as wind and rain penetration, glazing safety standards, materials and finishes.

Education programs on energy conservation and renewable energy, in addition to specialised training courses on advanced window technology for industry, help raise awareness and competence in the marketplace. One powerful approach is for manufacturers to market advanced windows on the basis that they can equal or outperform walls or roofs. For example, superwindows or transparent insulation materials (TIMs) having U-values below $1W/m^2.K$, return a net energy gain in any climate. In hot climates “cool daylight” glazings or electrochromic systems, coupled with continuous dimming have been shown (Project A2/A3) to outperform single glazings and external shades on the basis of total building energy use and capital costs. As well as cost benefits, the amenity value of increased usable space and improved comfort levels (and associated increase in occupant satisfaction, resulting in, in commercial buildings, increased productivity) should be considered.

The activities undertaken within this project will assist educators, industry, the consumer and the environment to gain the maximum benefit from emerging advanced window technologies. The project is by no means complete. The most serious factors which have impeded completion of the project in its originally conceived form are (a) lack of resources and commitment from the members countries, and (b) the volume of information generated by the Task, much of which has been in the final phase of the work. There is clearly a serious need to press on with the job of processing this information and finding new resources to aid its dissemination and enhance the impact of the Task on a wider audience. For example, much more work will be done by Australia during 1997 and beyond, principally guided by the Australasian Window Council.

6. APPLICATIONS AND COMMERCIALISATION

6.1 Introduction

Some important applications for the advanced glazing technologies that have emerged from Task 18 have been. In most cases, the performance of a given glazing system has been identified using computer simulation of the energy impact of the system on prototypical buildings. The climatic suitability of a glazing depends on a number of tradeoffs between its solar transmittance, thermal transmittance, visible transmittance, etc. In the case of electrochromic (dynamically switchable) windows, more flexible operation is possible where the glazing's properties are controlled by a system linked to other parameters such as solar irradiance or air temperature. Many such scenarios were studied by means on computer simulation during the Task. The applications and the extents of their commercialisation has been substantial and are summarised in the following section.

6.2 Refinement of Australia's Nationwide House Energy Rating Scheme

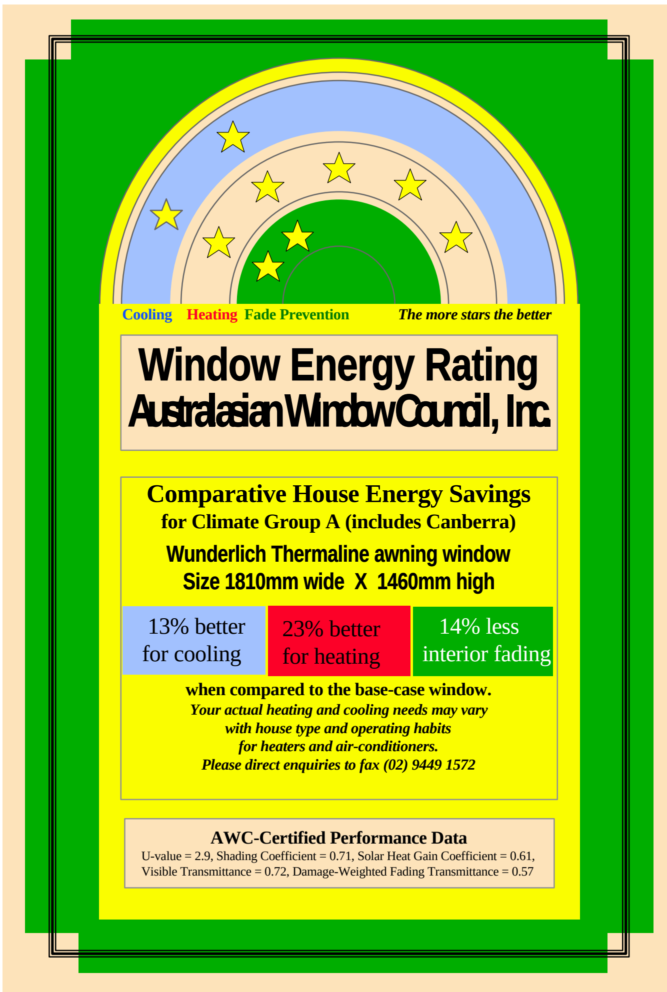
The Nationwide House Energy Rating Scheme (NatHERS) is Australia's benchmark system for predicting the annual energy performance for heating and cooling in houses and small buildings. Developed under an ANZMEC[6] agreement between all states and territories and coordinated by the Department of Primary Industries and Energy, the project has been managed by the Subtask A Leader for Task 18. An increasing number of Australia's local government authorities are referencing NatHERS as their sole means of assessing compliance with minimum energy efficiency.

As window energy behaviour became better understood as a result of Task 18 studies, this knowledge was fed into the simulation program (CHENATH) that NatHERS uses. In particular, the angular dependence of solar transmittance, solar reflectance and solar absorptance was incorporated into the CHENATH algorithms to ensure that the overall software was equal to other leading packages such as DOE-2 and ESP. CHENATH is the simulation engine used for the Window Energy Rating Scheme and thus the two schemes have a symbiotic relationship: the performance data for rated windows are accessed directly by NatHERS so that actual rated windows may be selected when a house design is being rated.

Left: The logo for the Australian Nationwide House Energy Rating Scheme (NatHERS) software. The software is the rating tool for predicting the annual energy performance for heating, cooling and comfort hours for houses and small buildings anywhere within 28 climate zones defined for Australia. Windows rated under the Window Energy Rating Scheme (WERS) can be directly 'plugged into' a house being rated under NatHERS. The scheme's development was funded jointly by the federal Department of Primary Industries and Energy (DPIE) and all states and territories. DPIE also part-funded the foundation technical development of Window Energy Rating Scheme.

[6] Australian and New Zealand Minerals and Energy Council

6.3 Advent of Australia's *Window Energy Rating Scheme (WERS)*



The underlying support of Task 18 raised the profile of Australian researchers in the eyes of local industry and had been instrumental in helping to secure funding for the development of the Window Energy Rating Scheme (WERS) with all its expected benefits for our industry, consumers and the environment. The scheme's technical development was funded by the Department of Primary Industries and Energy and by the industry members of the Australasian Window Council, who collectively represent almost all the architectural glass and residential windows sold in Australia today.

WERS ranks residential windows for their energy impact on typical housing anywhere in Australia. It tells the user whether a given window is suitable for the climate or not. It rates windows on their own, without attachments like curtains or blinds, so that an unambiguous comparison may be made between basic competing options. It is planned that WERS will be augmented to include applied [stick-on] films, blinds and skylights later in 1997.

Rated windows receive one to five stars for each of cooling (summer), heating (winter) and interior fade protection, depending on how they rank against the alternatives. A window can receive a Generic Rating by assigning it to a 'pigeon hole' based on its overall construction, *or* a Custom Rating where the window's specific materials are used to arrive at a unique rating. This is the preferred option for those who wish to differentiate their product from others.

WERS complements manufacturers' existing standards for wind, water and safety (AS 2047). It is independent of any one manufacturer and is advisory only, and acts as a fair, rigorous and credible system for testing performance claims. The scheme has been launched in the Canberra region; in 1997 it will be extended to the rest of Australia and to New Zealand. All major window and glass companies in have agreed to embrace WERS and use it to help add another new level of quality assurance to their products.

The scheme spells the end of selling windows on price alone - real value comes from a product that does its job properly.

The procedure used by WERS to calculate the percentage improvements in heating and cooling energy, and hence the star ratings, is similar to that of the National Fenestration Rating Council (NFRC) in the USA. WERS and the NFRC are examples of internationally-coordinated R&D leading to a harmonised system for rating windows.

6.4 Formation of Australasian Advanced Windows Group and the Australasian Window Council

The Australasian Advanced Windows Group (AAWG) was formed in 1991 to support windows technology transfer (arising out from Australian involvement in Task 18) to the local window and glass industry, and to provide a framework for industry training and education about emerging advanced glazing technologies. It helped inspire a similar organisation in the UK – the Advanced Glazing Industry Club. In 1996 the original Australasian Advanced Windows Group was absorbed into the Australasian Window Council (AWC).

Although the early focus of the AAWG was very much on energy and comfort issues, its scope has broadened with the formation of the Australasian Window Council. The overall mission statement of the AWC is “to develop, implement and manage an industry-wide quality assurance system for the window products industry in Australia and New Zealand”. As in most countries, the impact of new window technology in Australia and New Zealand has emphasised quality accreditation, environmental impact, standards initiatives and consumer demands for greater comfort.

In establishing the AWC, it was recognised that in the United States and the United Kingdom the introduction of new technology and accompanying legislation has had a considerable impact on the existing marketplace, some of which has caused severe problems, e.g. insulating glass failures and wood preservative failures (UK) and U-value standards (California). Meanwhile, Australia has had a very fragmented approach to maintaining high standards for consumers to enjoy. State-by-state parochialism, political differences and a widely-scattered population have all exacerbated this trend. Another problem is the tendency of industry to become fragmented into rival lobby organisations, such as uPVC-versus-wood-versus-aluminium windows. In legitimately defending market shares, this competition (with its conflicting claims) also confuses the consumer and retards progress towards new standards. Independent credible benchmarks are needed to assess claims about window energy performance - hence the development of the unified Window Energy Rating Scheme for Australasia, along the lines of the NFRC’s, but not the same. This is but the first of a number a quality assurance-related projects that the AWC will coordinate. It is an example of the strategy of integrating exemplary energy performance into the quality assurance programs to complement non-energy issues such as wind and rain penetration, glazing safety standards, materials and finishes. Real progress has already been made by Australia’s

Residential Window Association in the adoption of a national window weathertightness-labelling scheme (similar to New Zealand's successful system) identifying the performance and national accreditation of their products.

The AAWG publishes a newsletter three times a year, *A Window to the Future*, which is the only cross-disciplinary publication of its kind dealing window energy technology that is published in Australasia. The AAWG is an industry-research club whose membership peaked at over 100 organisations across Australia and New Zealand. The AAWG provides liaison and technical backup for industry and other Australian companies and universities, whether or not they have been involved directly in Task 18. Since its formation in 1991, the group has strengthened awareness of the role that windows play in determining the comfort and energy performance of buildings. Against a background of specialist seminars, professional University Certificate Courses at the University of New South Wales and the news and technical features that the newsletter provides, local researchers and industry are producing world-leading results, some of which are already emerging in the form of innovative new products and standards. These are described below.

The newsletter contains a blend of industry news, technical features and snapshots of R&D worldwide, particularly in Task 18 and the NFRC. For example, members may order Task 18 technical reports and papers from the newsletter. Task 18 quickly adopted the use of the Internet to enable its participants to communicate easily by email, as they are scattered across 15 countries. The Task maintains identical file (FTP) sites in Canberra and Rome to facilitate exchange of Task documents. More recently, a general IEA 'home page' has been set up in New Zealand on the World Wide Web at http://www-iea.vuw.ac.nz:90/task18.html.

The rapid growth in the use of the Web by business means that industry has a powerful new tool for advertising, providing applications guidance materials and keeping in touch with the research community as well as its peers.

The AAWG holds twice-yearly seminar days and training workshops for premier software packages used to predict the energy performance of windows: WINDOW 4.1 from the USA and FRAMEplus from Canada To reinforce the knowledge base of the AAWG, since 1992 the University of New South Wales has conducted with industry a Professional Development Course in Window Design and Performance Technology. This certificate course has been targeted at management, senior technical and sales/marketing personnel from leading glass and window companies in Australia and New Zealand. Courses cover structural, safety, legal, quality assurance and weathertightness issues in addition to energy performance.

In 1994 the Australasian Window Council was formed as the peak body for the window products industry in Australia and New Zealand. Its first major initiative was the development of the Window Energy Rating Scheme (described in Section 7.2).

6.5 World's first commercially available vacuum windows

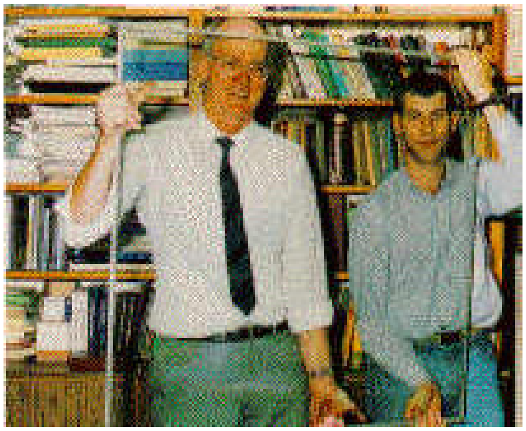


Figure 8. Professor Dick Collins (left) and Mr Tom Simko display a 1-square-metre prototype vacuum glazing panel, developed at the University of Sydney. A centre-glass thermal transmittance of less than 1.2 $W/m^2.K$ has been achieved along with high solar transmittance (if desired). Two panes of Pilkington K glass are employed to minimise radiant heat loss while the evacuated space eliminates convective heat transfer. Important supporting analysis and measurements have been carried out at University of Ulster at Jordanstown, Northern Ireland and at the Infrared Thermography Lab at Lawrence Berkeley National Laboratory, California. The technology has since been commercialised by Nippon Sheet Glass in Japan.

Photo: University of Sydney

The Task's Project B5 *Evacuated Glazing,* led by Professor Dick Collins at the University of Sydney, has resulted in the world's first commercialised vacuum window systems being introduced to the Japanese domestic market this year by Nippon Sheet Glass under the name *Spacia*™. These sealed vacuum window units are being targeted at the residential retrofit market at a price which is highly competitive with conventional sealed double glazing. They can achieve far superior performance, on a par with current 'superwindows', in the more highly specified form which employs two hard low-e coatings. The thermal transmittance (U-value) achieved in that specification is approximately 1 $W/m^2.K$ — more than 80% below that of clear single glazing. The patent for this technology is retained by the University of Sydney and therefore Australia retains control of the technical future of this important development.

6.6 Angular-selective glazings for cooler, more comfortable commercial buildings

Project B7 *Angular-Selective Glazings,* led by Professor Geoff Smith and Associate Professor John Bell at University of Technology Sydney, has produced prototype glazings which retain views and daylight while reducing unwanted solar heat gain. Professor Smith's group has worked closely with Sustainable Technologies Australia (STA) to develop the sol-gel process for applying thin-film coatings to architectural glazings. The project addresses the huge benefits to be gained by the use of daylight to displace electric light in non-residential buildings.

Figure 9. Clarity of view is a feature of the STA switchable window, seen here against the Queanbeyan skyline. The STA Smart Windows project was assisted by ERDC support via Task 18 and a special-purpose grant.
Photo: STA Ltd 1996

The participation of Australia in Project B3 *Low-e Coatings* (led by Sweden) was of invaluable assistance to the Australian Smart Windows project. The participants in B3 represented all the major research groups working in this area, and the interaction provided an opportunity to benchmark the Australian research and to be involved in the development of test methods, especially the testing of many competitive products.Without this participation, the project would not have reached its current stage of scaling up to precommercial pilot-production stage.

6.7 Innovative 'cool daylight' skylights

Project B8 *Daylighting Systems* was led by Dr Ian Edmonds of Queensland University of Technology. A major outcome of this project was the Laser-Cut Panel (LCP) which deflects sunlight from some angles while admitting light from others. The LCP has been applied in world-leading products, now commercialised in Australia by the Sydney-based company Sky Solutions. The products include a pyramid-shaped roof skylight and the Skytube® mirror-tube skylight. The company's products are now being exported to Germany.

In October 1995, acrylic angular-selective skylights were installed in a twin classroom at Waterford State Primary School, Queensland. The immediate response from the school was very positive, with the skylighting eliminating the need for supplementary lighting and providing much more natural illumination well above the minimum required levels, even in overcast conditions.

The longer-term objective of the research group is to develop daylighting systems for large multi-storey buildings. This is a challenging problem requiring an integrated approach with architects and other building specialists. These researchers include those at University of Technology Sydney who have benefited from participation in Task 18.

Figure 10. Laser-cut light deflecting panel incorporated in pyramid form inside the clear cover of a conventional skylight. The Laser-Cut Panel deflects low-elevation light down into the room but rejects high-elevation light by double reflection. The skylight becomes angular-selective with the result that the illuminance below is much more even over the course of the day.

6.8 Stengthening of other vital international R&D links

One of the authors (PRL) is the IEA representative on the U.S. National Fenestration Rating Council (NFRC) and chairs its International Liaison Subcommittee The NFRC is a non-profit organisation formed in 1989 in the United States by Act of Congress to develop a system for rating the energy performance of windows, doors and skylights. It does not enforce codes or performance standards but instead provides a framework by which window products may be compared with each other on a scientifically rigorous and independent basis. It is a cooperative effort between the window-products industry, energy utilities, state energy offices, consumer and environmental groups, and the United States Department of Energy (DOE).

Throughout most of the life of Task 18, continuing valuable liaison occurred with the NFRC. Reciprocally, technical knowledge gained by attending NFRC meetings has been of great assistance (for example) in refining Australia's WERS and in developing better methods for identifying applications for advanced glazing systems. Lawrence Berkeley National Laboratory is a key U.S. participant in Task 18 via Project A2/A3 *Modelling & Control Stategies* and is a regular contributor on NFRC technical subcommittees.

7 SUMMARY OF KEY TECHNOLOGICAL FINDINGS FROM SUBTASK B

8 CONCLUSIONS

9 ACKNOWLEDGMENTS

10 REFERENCES